Reprinted from 2000 *Columbia Basin Agricultural Research Annual Report. Spec. Rpt. 1012,* pp. 79-93, 2000
Oregon State University in cooperation with USDA-Agricultural Research Service, Pendleton, OR

ROOT-LESION NEMATODES IN EASTERN OREGON DRYLAND CROPS

Richard W. Smiley

Introduction

Nematodes are roundworms that occur worldwide in all environments. Most of the estimated 500,000 species are beneficial to agriculture in that they contribute to decomposition of organic matter and are important members in the food chain. Some species are parasitic to plants or animals. About 15 percent of the 15,000 nematode species currently identified are plant parasites. The plant-parasitic species cause an estimated annual crop loss valued at $8 billion in the U.S. and $78 billion worldwide (Barker et al., 1998). Most of the plant parasites are tiny (less than one millimeter long; 0.04-inch) and live in soil (Barker et al., 1998; Evans et al., 1993; Jenkins and Taylor, 1967). This paper addresses the parasitic group (*Pratylenchus* species) commonly known as root-lesion nematode (Figure 1). This name relates to the type of damage they cause on roots. The species *P. penetrans* is notorious for causing extensive damage to a broad range of crops and ornamentals in western Oregon, and on irrigated high-value crops such as potato, mint, and alfalfa in eastern Oregon (Jensen, 1961). Lesions created by nematodes provide additional opportunities for infection of roots by fungal pathogens. Special control measures are required for controlling nematodes in many crops. A more detailed description of root-lesion nematodes is provided in the addendum to this paper.

For many years it has been thought that root-lesion nematode populations occur at numbers low enough to be of little concern in dryland winter wheat/summer fallow rotations in the inland Pacific Northwest (PNW). However, there is increasing evidence that these tiny soil animals can affect non-irrigated crops adversely, and that damage symptoms can be confused with symptoms of nutrient deficiency, drought, or root disease.

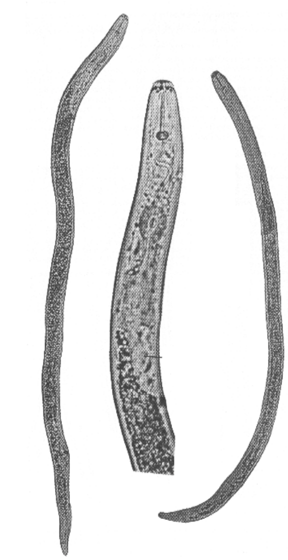

Figure 1. Microscopic photographs of two full-length, mature *Pratylenchus* females (body length is 0.5 mm, or 0.02 inch), and a higher magnification (center) showing the feeding stylet on the anterior portion for another *Pratylenchus* female (modified from Mai and Lyon, 1975).

Two recent reports describe root-lesion nematodes as potentially important parasites of dryland wheat in the PNW. *P. thornei* and *P. neglectus* were detected in winter wheat near Walla Walla (Mojtahedi et al., 1986; Mojtahedi and Santo, 1992). Follow-up tests with *P. thornei* in the greenhouse showed that it could reduce growth of winter wheat. Both *P. thornei* and *P. neglectus* now are recognized for causing severe damage to wheat and other crops in non-irrigated regions of Australia (Doyle et al., 1987; Taylor et al., 1999; Vanstone et al., 1998). *P. thornei* on wheat also causes severe stunting and reduced grain yield and test weight in eastern Colorado (Armstrong et al., 1993), Utah (Sher and Allen, 1953), southern Ontario (Yu, 1997), the Negev area of Israel (Doyle et al., 1987), and the Sonora district of Mexico (Doyle et al., 1987). At least eight species of root-lesion nematodes in the genus *Pratylenchus* have been recorded on small grains in other regions or countries (Griffin, 1984; Rivoal and Cook, 1993).

This paper brings together several reports of high lesion nematode populations in non-irrigated fields in the PNW, and relates those reports to research findings in comparable cropping systems in other states or countries. This paper also summarizes results of a preliminary survey of lesion nematode populations in dryland fields in eastern Oregon during 1999. An intensive nematode sampling was conducted during the final year (1999) of a crop rotation experiment near Pilot Rock. Less intensive samplings also were performed in other fields and experiments in eastern Oregon and Washington.

Methods

Reports prior to 1999

It is common for Extension pathologists to collect a diverse and quite random group of reports that may not have special importance beyond the field immediately affected. However, trends and new insights are often possible when these reports are viewed collectively. A small group of randomly collected observations are brought together in this paper.

Sampling in 1999

Soil and plant samples were collected for assessment of root-lesion nematode populations at four Oregon locations (Moro, Echo, Pendleton, Pilot Rock) and one Washington (Ralston) location during the summer of 1999.

Nematode Sampling Procedure

At each location, cores of soil plus roots were collected directly in the crop drill rows, using the method described by Armstrong et al. (1993). Cores were 2.5-cm diam x 10-cm depth (1-inch x 4-inch). Twenty cores were collected for each plot or field and were mixed in a single bag. Samples were stored in a refrigerator and soil was passed through a 4-mm (0.16-inch; Tyler #5) sieve and mixed before nematode extraction. At two locations, 20 root systems in each experimental treatment also were collected separately by shovel to an 8-cm (3-inch) depth. Nematode extraction and identification were performed by Kathy Merrifield at the OSU Nematode Diagnostic Lab at Corvallis, using a standard wet-sieving density-floatation method to extract soil-dwelling nematodes and a standard 7-day root-mist procedure to extract endoparasitic nematodes from roots (Ingham, 1994). The soil extraction procedure involves suspension of soil in water and, after allowing solids to settle for a precise time, pouring the liquid through a filter. Material retained in the filter is re-suspended and centrifuged. The pellet is re-suspended in a sugar solution and centrifuged again. The liquid containing nematodes is filtered again and examined under a microscope. Tedious observations of nematode body structures and dimensions are used to determine numbers and identities of the parasitic and beneficial species. To extract root parasites the roots are placed in a chamber and misted for 60 seconds every five minutes for seven days. Nematodes that migrate out of the roots are collected and observed under a microscope. Once generic or species identifications are complete, the numbers are normalized to equal units of soil or root mass. All numbers in this paper are reported as lesion nematodes per kilogram of soil (e.g., xx/kg soil), or lesion nematodes per gram of fresh root tissue (e.g., xx/g root). For comparative purposes, one pound equals 0.45 kg or 454 g.

Pilot Rock

Dr. Dan Ball, OSU weed scientist, conducted on-farm research at a site in a 300-mm (12-inch) rainfall zone near Pilot Rock (Ball et al., 2000). Farm-size equipment was used for the experiment, and best management practices were used for tillage, residue management, fertilizers, varieties, pesticides, and planting dates. Seven rotation treatments were established in 1994 and were replicated four times in a randomized complete block design. Rotations included continuous no-till spring wheat, spring barley/fallow/winter wheat with conventional or chemical fallow, fallow/canola/winter wheat with chemical fallow, and winter wheat/fallow with fallow prepared by moldboard plow, chisel, or herbicides. Madsen winter wheat was planted into all plots on September 30, 1998, the sixth year of the study. Samples of moist soil were collected on June 28, 1999, several weeks before harvest and 3 days after a rain (12-mm [0.5-inch]) in an otherwise very dry summer. Separate composite soil samples were collected from two replicates in each of the seven treatments. Root samples also were collected from both replicates.

Moro

Four experimental plots were sampled at the OSU Columbia Basin Agricultural Research Center (Sherman Station) near Moro. A single composite soil sample was collected from each plot. Soil was only slightly moist at the time of sampling on August 2. The crops included wheat, canola, and lupin. The wheat experiments involved annual no-till spring wheat planted for the third and fourth consecutive years (Smiley et al., 1999). Wheat was planted into these plots during March. The canola and lupin experiments also were planted during the spring, and followed summer fallow after winter wheat.

Echo

No-till spring wheat has been produced annually for 7 years at the 66 Ranch (operated by the Mader and Rust families) between Echo and Lexington (Smiley et al., 1999). In 1999, Alpowa soft white spring wheat was planted during March. A single composite soil sample was collected from the entire plot area. Soil was only slightly moist at the time of sampling on August 2.

Pendleton

Samples were collected from 14 plots at the OSU Columbia Basin Agricultural Research Center near Pendleton. A sample also was collected from an adjacent field of commercial winter wheat. The sites were selected at random to represent a broad range of cropping systems and current crops. These crops are summarized in Table 1. Unless indicated otherwise, all summer fallow plots are managed either by chisel plowing in the spring followed by multiple rod weedings, or by moldboard plowing followed by disking and rod weeding. Nematode samples consisted of a single composite soil sample for each plot. Soil was only slightly moist at the time of sampling on July 29.

Ralston

Dr. Frank Young, USDA-ARS weed scientist at Pullman, conducted on-farm research on a 20-acre site in a 280-mm (11-inch) rainfall zone near Ralston, Washington

(Smiley et al., 1999). Rotations were established with farm-size equipment during August 1995. Treatments included continuous spring wheat and rotations of spring wheat/spring barley, spring wheat/summer fallow, and winter wheat/summer fallow. Best management practices were used for tillage, residue management, fertilizers, varieties, pesticides, and planting dates. The plots are large plots and are replicated four times in a randomized complete block design. Soil and root samples were collected for each replicate of each treatment. Soil was very dry and hard when collected on July 28.

Results

Reports Prior to 1999

A wheat producer near Touchet, Washington asked me to assist in diagnosing reasons for poor crop vigor in no-till, annual hard-red spring wheat during the spring of 1987. I found Rhizoctonia root rot, but I did not consider the fungal pathogen entirely responsible for the absence of branch roots. I suspected nematode damage and sent a sample to the diagnostic lab at WSU-Prosser. Drs. Hassan Mojtahedi and Gerald Santo responded by sampling the spring wheat and nine other fields. They found *P. neglectus* in high numbers (2,900/g root) in roots of annual spring wheat, in lower numbers (30 to 440/g root) in six other fields, and undetected in three fields.

In the spring of 1988, several wheat breeding plots at the Columbia Basin Agricultural Research Center near Pendleton had poor spring greenup and uneven plant height. I collected samples from 16 fields at the center and submitted them for evaluation at the OSU Nematode Diagnostic Lab at Corvallis. Nematologists found high populations of *P. thornei* in three samples, including each of the wheat breeding plots that prompted the sampling. The highest population detected was 6,800/kg soil.

During the late 1980s, I conducted research on control measures for the cereal cyst nematode (*Heterodera avenae*) in the Grande Ronde Valley (Smiley et al., 1994). During the conduct of that research, on a farm east of La Grande during 1990, I found high populations of both root-lesion (9,000/kg soil) and cereal cyst nematodes in a winter wheat/summer fallow rotation. That same year, at another farm north of La Grande, I investigated a field of unthrifty wheat following a canola crop and found lesion nematodes in high numbers: 30,800/kg soil. In 1992, at the research center near Pendleton, I discovered high populations of *P. thornei* (3,950/kg soil) in a sample taken from unthrifty wheat in a USDA-ARS winter wheat experiment. Wheat roots and soil collected from an unthrifty wheat crop in a winter wheat/green pea rotation near Athena, Oregon during 1998 were found to have mixtures of three *Pratylenchus* species; *P. neglectus, P. penetrans*, and *P. thornei*.

Extension Service faculty have shared with me several sampling reports indicating high lesion nematode counts. Gordon Cook, OSU-Union County, gave me a 1983 sampling report showing a very high population (25,600/g root) in a grass seed field that was experiencing production problems. Mike Stoltz, formerly OSU-Umatilla County, gave me a 1993 data sheet showing a high population (34,600/kg soil) in a seedling alfalfa field experiencing production problems. Larry Smith, UI-Nez Perce County (Lewiston), gave me a 1992 report showing high lesion nematode populations (up to 112,000/kg soil) in a field recropped to wheat for 20 years.

Sampling in 1999

Rainfall was sparse during the spring at locations where samples were collected for this survey. Moro, for example, had 46 percent less precipitation than the 20-year seasonal mean for the spring. Therefore, soils were quite dry when collected at all locations except Pilot Rock, where sampling occurred 3 days after a rain (12 mm [0.5 inch]) in an otherwise dry spring and summer. A mixture of *P. neglectus* and *P. thornei* was present at Pilot Rock (Table 1). *P. neglectus* was the only species extracted from roots and was the dominant lesion nematode in soil. Numbers in the winter wheat treatments were highest in the 3-year rotation that included canola (303/kg soil; 4,369/g wheat root) and lowest (7 to 25/kg soil; 127 to 305/g wheat root) in the 3-year rotation that included barley and summer fallow. Intermediate numbers (167/kg soil; 1,059/g root) occurred in annual spring wheat. Nematode numbers were generally lowest in rotations where winter wheat was produced once in 3 years rather than every other year or annually. Although wheat yield at Pilot Rock was inversely associated with lesion nematode populations in roots and soil (Figure 2), it is not clear whether yields responded more to numbers of lesion nematodes or to variable soil moisture available in each treatment. It is interesting, however, that similar yield versus treatment trends occurred in these treatments during earlier years when drought was not a factor. The relationship between grain yield (y; in bushels/acre) and the logarithmic transformation for numbers of nematodes in roots (x; expressed as log *P. neglectus*/g root) or in dry soil (x; log *P. neglectus*/kg soil) at Pilot Rock were $y = 53.4 - 11.1x$ for roots ($r^2=0.56$; $p<0.01$) and $y = 37.7 - 3.6x$ for soil ($r^2=0.35$; $p=0.03$).

P. neglectus was the only lesion nematode species identified in annual no-till spring wheat experiments at Moro and Echo (Table 1). Populations in spring wheat at Moro (1,090 and 2,570/kg soil) were much higher than in nearby canola (140/kg) and lupin (20/kg) crops planted into summer fallow (14 months) following winter wheat.

Both *P. neglectus* and *P. thornei* were detected at Pendleton. Populations in soil were highest in the long-term annual spring (3,970/kg soil) and winter (1,610/kg soil) wheat experiments (continuous since 1930) and an experiment with recrop canola following winter wheat (910/kg soil). Populations were lowest (less than 50/kg soil) in rotations of winter wheat following summer fallow, spring barley following canola, and no-till spring wheat following winter wheat.

Lesion nematodes were not detected in samples from Ralston, even though root lesions and root pruning typically produced by root-lesion nematodes were present during root disease assessments earlier in the spring.

Discussion

Failure of crops to yield to their full potential because of damage from nematodes depends on the species and numbers of nematodes in roots, crop species and variety, crop growth stage, crop rotation and tillage management, activity of fungal pathogens, and soil temperature, moisture and texture. Models to predict crop damage require intensive research and are often impossible to generalize over regions with variable soils, climates, and cropping systems. Very little research is conducted on nematode pests of crops with comparatively low per-acre value. Prediction of potential damage

Table 1. Root-lesion nematodes in Oregon fields during July and August 1999.

Nearest town	1998 crop[1]	1999 crop[1]	Lesion nematodes[2] in soil		Lesion nematodes[2] in roots	
			- no./kg -		*- no./g -*	
Pendleton	SW	SW	3,970	Pt	-	-
Moro	no-till SW	no-till SW	2,570	Pn	-	-
Pendleton	WW	WW	1,610	Pn	-	-
Moro	no-till SW	no-till SW	1,090	Pn	-	-
Pendleton	WW	Canola	910	Pn	-	-
Pendleton	WW	Pea	730	Pt/Pn	-	-
Echo	no-till SW	no-till SW	590	Pn	-	-
Pendleton	Pea	WW	570	Pn	-	-
Pilot Rock	Canola	WW	303	Pn/Pt	4,369	Pn
Pendleton	SW	no-till SW	290	Pn	-	-
Pilot Rock	no-till SW	no-till SW	167	Pn/Pt	1,059	Pn
Moro	WW	Canola	140	Pn	-	-
Pendleton	Lupin	SW	110	J2	-	-
Pendleton	SW	no-till SW	100	Pn	-	-
Pendleton	SB	SB	90	Pn/Pt	-	-
Pilot Rock	fallow	WW	51	Pn	253	Pn
Pendleton	WW	no-till SW	50	Pt	-	-
Pilot Rock	fallow	WW	39	Pn	244	Pn
Pendleton	Canola	SB	30	Pn	-	-
Pendleton	fallow	WW	30	J2	-	-
Pendleton	SW	WW	30	J2	-	-
Pilot Rock	fallow	WW	29	Pn/Pt	543	Pn
Pilot Rock	fallow	WW	25	Pn	305	Pn
Moro	WW	Lupin	20	Pn	-	-
Pendleton	fallow	WW	10	J2	-	-
Pilot Rock	fallow	WW	7	Pn	127	Pn

[1] Crops: SW = spring wheat; SB = spring barley; WW = winter wheat

[2] Lesion nematodes: Pn = *Pratylenchus neglectus*; Pt = *P. thornei*; J2 = identification of *Pratylenchus* species was not possible because juvenile stages were present, but adults were not.

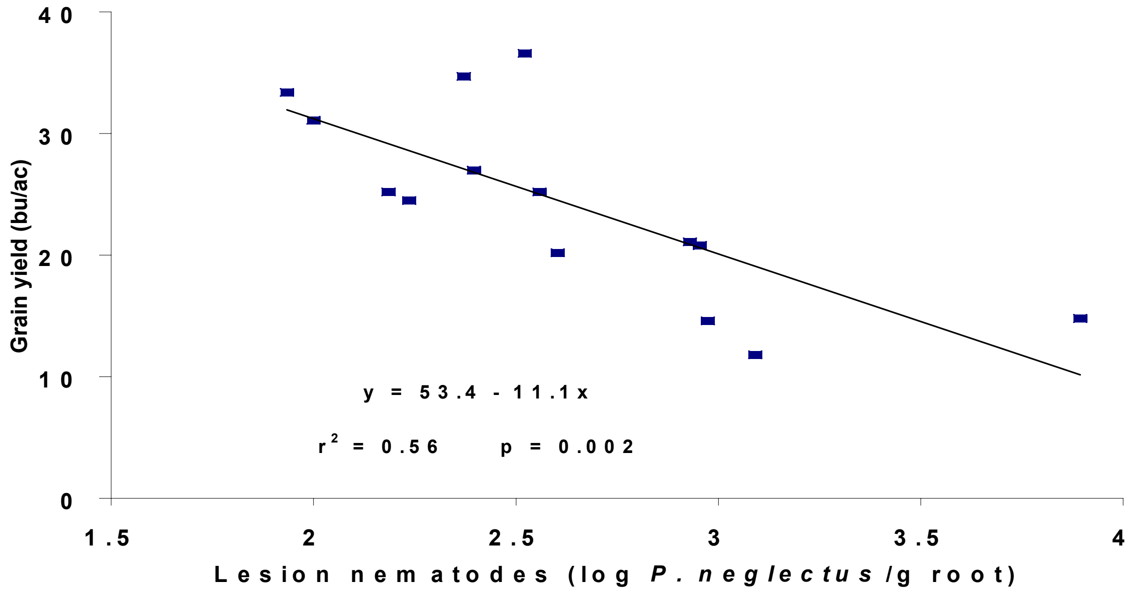

Figure 2. Wheat yield and numbers of *Pratylenchus neglectus* in wheat roots following the 1999 harvest in a crop rotation and weed management study near Pilot Rock, OR; y = yield in bushels/acre, x = logarithmic transformation for numbers of *P. neglectus*/g root, r^2 = correlation coefficient, p = degree of statistical confidence.

from lesion nematode population estimates requires additional research in the region.

Although precise interpretation is not possible for root-lesion nematode numbers in dryland crops and soils in eastern Oregon, it is possible to compare local findings with perspectives reached through research in other regions. These comparisons indicated that *P. neglectus* and *P. thornei* were present in sufficiently high numbers to be considered potentially damaging in some crops at Pendleton, Echo, Moro, and Pilot Rock. Moreover, these nematodes always were found in combination with additional stresses from drought and/or fungal pathogens.

Comparisons with Cereals in Other Regions

Doyle et al. (1987) investigated a situation in which wheat yields were consistently low on certain fields in Australia. Wheat plants over entire fields were stunted, had reduced tillering, and sometimes had yellowing of the lower leaves. Grain yields were commonly half of what was expected in the region. All affected fields had clay soils and had been cultivated for a minimum of 10 years. Application of the nematicide aldicarb (Temik•) reduced *P. thornei* numbers from 400/kg soil to zero and increased yield of nematode-susceptible wheat by up to 51 percent and nematode-resistant barley by 10 percent. As a comparison, the population of *P. thornei* wheat at the Pendleton Station during 1999 was 10 times higher (nearly 4,000/kg soil) in a plot of long-term annual spring wheat. Nematicides have not been applied to the Pendleton plots to determine if lesion nematodes are restricting yield potential.

Populations of *P. thornei* in the Negev area of Israel have been reduced 90 percent by rotating wheat with 2 years of summer fallow (Griffin, 1984; Rivoal and Cook, 1993).

Adequate control of *P. thornei* and increased wheat yield in Mexico were achieved with a combination of crop rotation, planting after the soil became cooler than 16°C (60°F), and proper soil fertility (Griffin, 1984). A strong negative correlation between grain yield and lesion nematodes (5,300 *P. thornei*/kg soil) was reported (Armstrong et al., 1993) in a winter wheat field recropped a second year without rotation to summer fallow in northeast Colorado. Soil fumigation reduced the nematode count to 500/kg soil and was correlated with winter wheat yield increases up to 50 percent. Armstrong et al. urged agronomists to consider these findings as they interpret results of field research on winter wheat in the central Great Plains. At Pendleton and Pilot Rock during 1999, lesion nematode populations were also generally higher as the frequency of wheat in the rotation was increased. An exception at Pilot Rock was the high population of nematodes in the 3-year rotation of summer fallow, winter canola, and winter wheat. Low levels of soil disturbance may have contributed to high lesion nematode numbers in that rotation, because it was maintained as a chemical-fallow, high-residue management system.

Wheat roots with lesion nematode numbers as low as 300/g root have been considered highly infested in some studies (Griffin, 1984; Rivoal and Cook, 1993). In a field with 100/g root at the time of harvest, fumigation of soil with metham-sodium controlled root-lesion nematodes and increased the yield of the following crop by 70 percent. Winter wheat in all rotational sequences examined in our experiment at Pilot Rock exceeded the lowest infestation level (100/g root) known to respond to nematode control measures in tests reviewed by Griffin and by Rivoal and Cook.

Interaction of Lesion Nematodes and Fungal Pathogens

Root tissue wounded by lesion nematodes often leads to greater damage by fungal pathogens (Taheri et al., 1994). Cereal root pathogens favored by interactions with lesion nematodes include fungi that cause Rhizoctonia root rot, take-all, Fusarium foot rot, Pythium root rot, and common root rot. In southern Ontario, *P. neglectus* is associated closely with Rhizoctonia root rot of winter wheat in lighter soils (Benedict and Mountain, 1956). Although the fungal pathogen was considered most important, it was thought that *P. neglectus* helped initiate the root rot disease. Multiplication rates of lesion nematodes also were found to be amplified when they entered root tissue already breached by fungal pathogens. For instance, pathogens causing Rhizoctonia root rot and take-all each were found to increase lesion nematode reproduction in roots. However, when these fungi both occupied the same root tissue, the combination greatly reduced nematode reproduction. This apparently occurred because the roots were so heavily damaged by the fungi that there were few healthy cells available for nematode feeding and multiplication. Interactions of fungal pathogens and nematode parasites have not been studied in non-irrigated crops in eastern Oregon. It is true, however, that fungal pathogens prevalent at sites sampled for nematodes during 1999 included those that cause Rhizoctonia root rot, take-all, Fusarium foot rot, and Pythium root rot.

Genetic Resistance to Lesion Nematodes in Cereals

Scientists in South Australia observed that two wheat varieties exhibited superior growth over other wheat varieties in field trials during 1996. Further research revealed that this was a response to genetic resistance to root-lesion nematodes. Vanstone et al.

(1998) reviewed literature showing that wheat varieties with resistance to *P. thornei* can yield twice that of intolerant varieties in soil with high populations of the nematode. They also stated that yield losses up to 85 percent have been reported in infested soils and that reduced tillage favors development of these nematodes. Vanstone et al. grew nine wheat varieties with varying levels of resistance at three sites infested with 1,000-6,000 *P. neglectus*/kg soil and one site with 33,000 *P. thornei*/kg soil. The variety Excalibur (resistant) yielded 20 percent more than Spear (susceptible) and resulted in 60 to 70 percent fewer nematodes in roots. Moreover, yields for the nine varieties were significantly and inversely correlated with nematode numbers in soil at the time of heading, 4 months after planting. Trend lines for correlations in their wheat variety study (for example, $y = 2.47 - 0.01x$; where y = grain yield in kg/plot and x = *P. thornei*/g dry soil) were similar to that found in our survey at Pilot Rock.

Farsi et al. (1995) examined the genetics and sources of resistance to root-lesion nematodes in wheat, rye, and triticale. They found the genetic mechanisms conferring resistance or tolerance to *P. neglectus* were not effective against *P. thornei,* indicating the necessity for pyramiding multiple sources of resistance into varieties produced in areas where both species may be important. Varietal screening tests indicated that cereals growing in a naturally infested field had vastly different levels of infestation in roots 3 to 4 months after planting (Vanstone et al., 1994). Different wheat varieties had 20-fold differences in numbers of nematodes per gram of root tissue, indicating very large differences in genetic potential to restrict *P. neglectus* multiplication in roots. Triticale roots contained fewer nematodes than the majority of wheat varieties and was recommended as a useful rotation crop in highly infested soils. Barley, durum and rye also had lower nematode reproductive efficiency than the majority of wheat varieties.

Host Range and Rotational Effects

Lesion nematodes have wide host ranges. *P. neglectus* infects all cereals as well as rotational crops such as grain legumes, pasture legumes, and oilseeds (Vanstone et al., 1994). However, nematode multiplication differs greatly in roots of various crop species and among varieties within each species (Taylor and Vanstone, 1996). Resistant varieties reduce nematode multiplication even though nematodes successfully invade their root system. Tolerant varieties allow multiplication and can carry high numbers of nematodes, but plants remain thrifty and yield well. Growth and yield are strongly reduced when roots of susceptible, intolerant varieties are invaded by nematodes. Knowledge of these relationships have important implications for crop rotation strategies, as production of each crop and variety will result in varying populations of nematode available to attack subsequent crops.

Sharon Taylor and Vivien Vanstone (personal communications; 1999) further demonstrated in field trials that the effect of *P. neglectus* on crop yield is highly dependent on the type of crop grown. These South Australian scientists performed their tests by applying or not applying aldicarb to soil that had pre-plant *P. neglectus* populations of 1,000/kg soil. The following ranges in yield reductions were noted for different varieties within each crop species: chickpea (0 to 43 percent), canola (0 to 27 percent), wheat (0 to 17 percent), pea (0 to 16 percent), barley (0 to 11 percent), oat (0 to 11 percent), durum (9 percent), and triticale (3 to 6 percent). They considered rye, triticale, safflower, lupin, and pea as poor hosts that may help reduce *P.*

neglectus numbers in soil for the next crop. Barley and lentil were intermediate hosts. Chickpea and wheat varieties were highly variable, with some being good hosts that increase *P. neglectus* numbers in soil.

Hollaway and Eastwood (1997) reported that plots planted to five barley and two durum varieties had lower numbers of *P. thornei* (800 to 2,000/kg soil) than all except the most resistant varieties of wheat (1,800 to 9,000/kg soil) in northwest Victoria, Australia. Six lentil and seven field pea varieties also had comparatively lower populations (500 to 2,200/kg soil). Intermediate populations occurred in plots of faba bean (3,500 to 4,100/kg soil), and high populations developed in plots planted with two vetch varieties (7,800 to 17,000/kg soil). Holloway and Eastwood considered pea and lentil as resistant, faba bean moderately susceptible, and vetch highly susceptible to multiplication of *P. thornei*. The nematode population increased during production of all wheat varieties except the few with resistance. Results of research with lesion nematodes on crops in the wheat belts of South Australia and Victoria (by S. Taylor, V. Vanstone and G. Holloway) culminated in a ranking system that lists crop species according to levels of resistance to multiplication by either *P. neglectus* or *P. thornei* (Table 2). Production of a resistant crop greatly reduces lesion nematode multiplication and limits potential for yield loss in subsequent crops that may be susceptible to damage.

In Australia, chickpea commonly is used as a nurse crop to encourage high populations of lesion nematodes on sites where experiments are to be performed. Chickpea also is used as the susceptible test crop at the end of rotation experiments to determine comparative influences on yield caused by varying populations of lesion nematodes. Chickpea yield in one test was 7 percent lower (0.1 tonne/hectare; 90 pounds/acre) following two years of a *P. thornei*-susceptible wheat variety than two years of a resistant variety. Nematode populations were especially high when chickpea was cropped two years successively after a *P. thornei*-susceptible wheat variety, resulting in 40 percent yield reduction (0.6 tonne/hectare; 550 pound/acre) compared to chickpea following 2 years of resistant wheat.

Table 2. Suitability of crop species for multiplication of root-lesion nematodes in South Australia and Victoria (modified from: Anon., 2000).

Crop	Host ability[1] for: *P. thornei*	*P. neglectus*
Chickpea	S	S
Wheat	S-MR	S-MR
Mustard	?	S
Canola	MR	S
Sub-clover	S	MR
Durum	MR	S-MR
Vetch	MS-S	MS-MR
Oat	?	MS-MR
Barley	MR-R	MS-MR
Medic	R	MS-MR
Lentil	R	MS-MR
Lupin	R	MR-R
Triticale	MR-R	R
Faba bean	MR-R	R
Rye	R	R
Field pea	R	R
Safflower	R	R

[1] S = susceptible, MS = moderately susceptible, MR = moderately resistant, R = resistant, ? = unknown. Resistant lines minimize nematode multiplication. Individual varieties of each crop can differ in resistance (e.g., wheat S-MR).

This report contains two observations of high *P. neglectus* numbers in wheat roots following production of canola: at La Grande in 1994 and Pilot Rock in 1999. Canola is considered a good to moderate host for *P. neglectus* and a poor host for *P. thornei* (Table 2). Canola supports levels of *P. neglectus* reproduction similar to susceptible wheat lines. However, it is also true that turning young canola into soil as a green manure can reduce nematode populations, and that reductions in nematode populations sometimes have been observed when canola is grown in rotations. Potter et al. (1998) examined mechanisms of lesion nematode suppression by *Brassica* species. Nematode suppression was due to release of glucosinolate compounds during decomposition, and was much more effective when released from buried foliar tissue than from roots. Potter (1997) reported that growth of *Brassica napus* resulted in nematode populations twofold higher than those found after oats (7,000 vs. 3,000/kg soil, respectively). However, within 1 week after the rape had been turned into the soil as a green manure, the nematode populations in the rape and oat plots were equal. Rape varieties that produced amounts of 2-phenylethyl glucosinolate above a specific critical level in root tissue resulted in greatly reduced numbers of lesion nematodes in root tissue. Concentrations of this natural biocide are highly variable among *Brassica* species and varieties, and among tissues within individual plants. Further selection of varieties with high levels of this glucosinolate in roots may improve the performance of canola and mustard as rotation crops grown for seed.

Much of the cultivated land in low-rainfall regions of the inland PNW currently is used to produce winter wheat during alternate years in a wheat/fallow rotation. A high-residue dust mulch commonly is used as the fallow, but increasing interest is being given to systems that include preparing fallow without tillage, producing spring cereals annually, and producing winter and spring wheat in rotation with crops such as canola, mustard, lupin, or lentil. Land in higher rainfall regions of the inland PNW typically is used to produce winter wheat in rotation with green processing peas, lentils, canola, mustard, grass seed, spring barley, or other crops. Further evaluations of root-lesion nematode populations and damage estimates appear to be important for cropping systems in the inland PNW.

Soil Sampling and Testing

Soil was especially dry and fractured when samples were collected at Ralston during 1999. No lesion nematodes were detected at that location, even though root damage ratings in the spring suggested the nematodes had been active earlier in the season. Recovery of root-lesion nematodes from dry soil is apparently poor and unreliable, because lesion nematodes survive dry soil conditions in a dehydrated, brittle state that is easily broken when dry soil is disturbed by sample collection procedures that fracture the soil structure (Taylor and Evans, 1998). Therefore, it is possible that population estimates in my survey during 1999 may have been low at most locations and particularly unreliable at Ralston.

Additional nematode sampling is recommended for non-irrigated crops in drier areas of Oregon and Washington, where there is increasing interest in producing crops with less frequent or no summer fallow. Nematode diagnostic services in Oregon are available at the OSU Nematode Diagnostic Laboratory at Corvallis (541-737-5540). Samples must be collected and handled carefully, because diagnostic procedures are based on extraction of living organisms that can be killed by mishandling. Descriptions of procedures for submitting samples to the lab are available at County Extension Service offices. Diagnostic services currently cost $25/sample to extract nematodes only from soil, $25/sample to extract nematodes only from plant roots, or $35/sample to extract nematodes from soil and roots. Information obtained from this base-level service is restricted to a reporting of numbers of each genera (*Pratylenchus*, for example) in soil or roots, and does not include identification of species within each nematode genus. Species identification is available for an additional cost of $10/genus/sample.

Conclusions

Root-lesion nematodes are present in many non-irrigated fields in the inland Pacific Northwest. While it is currently impossible to establish direct associations between nematode numbers and yield constraints for broad-acre field crops, there is an accumulating body of circumstantial evidence that lesion nematodes are imposing a negative impact on crop yields in at least some dryland cropping systems in this region. More emphasis is needed for surveys of parasitic nematodes and crop damage estimates in dryland fields. If yield constraints are demonstrated, it would be possible to introduce genetic resistance into new cereal varieties and to design crop rotations with this constraint in mind. It also would be possible to equip commercial laboratories with modern molecular diagnostic systems that can offer reduced sample processing time and reduced skill in nematode taxonomy, compared to the time and expertise currently required for workers in nematode diagnostic labs.

Acknowledgements

Drs. Dan Ball, Bill Payne, Don Wysocki, and Frank Young, coordinators of experiments from which many of the nematode samples were collected, are truly appreciated. Curtis Henning, Frank Mader, Tim Rust, Jeff Shaw, and Calvin Spratling, wheat producers whose fields were included in the sampling process during 1999, also are appreciated. I am also grateful for the excellent services provided by Kathy Merrifield (OSU Nematode Diagnostic Laboratory at Corvallis) and support received from Drs. Russell Ingham and Stella Coakley (Department of Botany and Plant Pathology).

References

Anonymous. 2000. Has no-till brought on Rhizoctonia—or is it root lesion nematodes? A “To The Point” report of research funded by the Grains Research & Development Corporation. Australian Grain 9(6):44.

Armstrong, J.S., F.B. Peairs, S.D. Pilcher, and C.C. Russell. 1993. The effect of planting time insecticides and liquid fertilizer on the Russian wheat aphid (Homoptera: Aphididae) and the lesion nematode (*Pratylenchus thornei*) on winter wheat. J. Kansas Entomol. Soc. 66:69–74.

Ball, D.A., R.W. Smiley, D.J. Wysocki, and M.A. Stoltz. 2000. Conservation crop rotations for dryland wheat in downy brome infested areas. Oregon Agr. Expt. Stn. Spec. Rpt. 1012:(this volume).

Barker, K.R., G.A. Pederson, and G.L. Windham (editors). 1998. Plant and Nematode Interactions. Agron. Monograph 36. Amer. Soc. Agron., Madison, WI.

Benedict, W.G. and W.B. Mountain. 1956. Studies on the etiology of a root rot of winter wheat in Southern Ontario. Can. J. Bot. 34:159–174.

Doyle, A.D., R.W. McLeod, P.T.W. Wong, S.E. Hetherington, and R.J. Southwell. 1987. Evidence for the involvement of the root lesion nematode *Pratylenchus thornei* in wheat yield decline in northern New South Wales. Austr. J. Exp. Agric. 27:563–570.

Evans, K., D.L. Trudgill, & J.M. Webster (editors). 1993. Plant Parasitic Nematodes in Temperate Agriculture. CAB International. Wallingford, UK.

Farsi, M., V.A. Vanstone, J.M. Fisher, and A.J. Rathjun. 1995. Genetic variation in resistance to *Pratylenchus neglectus* in wheat and triticales. Austr. J. Exp. Agric. 35:597–602.

Griffin, G.D. 1984. Nematode parasites of alfalfa, cereals, and grasses. *IN* Plant and Insect Nematodes. Nickle, W.R. (ed.). Marcel-Dekker Inc., New York. pp. 243–321.

Hollaway, G. and R. Eastwood. 1997. Root lesion nematode: tolerance, resistance, and management strategies: what did we learn in 1996. Crop Sci. Soc. S. Austr. Newsletter No. 157.

Ingham, R.E. 1994. Nematodes. *IN* Methods of Soil Analysis, Part 2. Microbiological and Biochemical Properties. Weaver, R.W. (ed.). Amer. Soc. Agron., Madison, WI. pp. 459-490.

Jenkins, W.R. and D.P. Taylor. 1967. Plant Nematology. Reinhold Publ. Corp. New York.

Jensen, H.J. 1961. Nematodes affecting Oregon agriculture. Oregon Agric. Exp. Sta. Bull. 579. 34 pp.

Mai, W.F. and H.H. Lyon. 1975. Pictorial Key to Genera of Plant-Parasitic Nematodes; 4th Edition. Cornell Univ. Press, Ithaca, NY.

Mojtahedi, H. and G.S. Santo. 1992. *Pratylenchus neglectus* on dryland wheat in Washington. Plant Dis. 76:323.

Mojtahedi, H., G.S. Santo, and J.M. Kraft. 1986. First report of *Pratylenchus thornei* on dryland wheat in Washington State. Plant Dis. 72:175.

Potter, M.J. 1997. *Brassica* tissue suppression of the root lesion nematode (*Pratylenchus neglectus* Filipjev). Proc. 11th Australasian Plant Pathol. Soc. (Perth). p. 259.

Potter, M.J., K. Davies, and A.J. Rathjun. 1998. Suppressive impact of glucosinolates in *Brassica* vegetative tissues on root lesion nematode *Pratylenchus neglectus*. J. Chem. Ecol. 24:67–80.

Rivoal, R. and R. Cook. 1993. Nematode pests of cereals. *IN* Plant Parasitic Nematodes in Temperate Agriculture. Evans, K., D.L. Trudgill, and J.M. Webster (eds). CAB Int•l. Wallingford, UK. pp. 259–303.

Sher, S.A. and M.W. Allen. 1953. Revision of the genus *Pratylenchus* (Nematoda: Tylenchidae). Univ. Calif. Publ. Zool. 57:441–470.

Smiley, R.W., R.E. Ingham, W. Uddin, and G.H. Cook. 1994. Crop sequences for winter wheat in soil infested with cereal cyst nematode and fungal pathogens. Plant Dis. 78:1142–1149.

Smiley, R., L. Patterson, K. Rhinhart, and E. Jacobsen. 1999. Disease management for annual crops in low-rainfall regions. Oregon Agric. Exp. Sta. Spec. Rep. 999:59–67.

Taheri, A., G.J. Hollamby, V.A. Vanstone, and S.M. Neate. 1994. Interaction between root lesion nematode, *Pratylenchus neglectus* (Rensch 1924) Chitwood and Oteifa 1952, and root rotting fungi of wheat. N.Z. J. Crop Hort. Sci. 22:181–185.

Taylor, S.P. and M.L. Evans. 1998. Vertical and horizontal distribution of and soil sampling for root lesion nematodes (*Pratylenchus neglectus* and *P. thornei*) in South Australia. Australasian Plant Pathol. 27:90–96.

Taylor, S.P. and V.A. Vanstone. 1996. Nematodes don•t have to be the root of all crop problems. Australian Grain 6(2):54–55.

Taylor, S.P., V.A. Vanstone, A.H. Ware, A.C. McKay, D. Szot, and M.H. Russ. 1999. Measuring yield loss in cereals caused by root lesion nematodes (*Pratylenchus neglectus* and *P. thornei*) with and without nematicides. Austr. J. Agric. Res. 50:617–622.

Vanstone, V., M. Farsi, T. Rathjun, and K. Cooper. 1994. Resistance of triticale to root lesion nematode in South Australia. Proc. 3rd Int. Triticale Symposium, Lisbon, Portugal. Kluwer Academic Press, The Netherlands.

Vanstone, V.A., A.J. Rathjun, A.H. Ware, and R.D. Wheeler. 1998. Relationship between root lesion nematodes (*Pratylenchus neglectus* and *P. thornei*) and performance of wheat varieties. Austr. J. Exp. Agric. 38:181–189.

Yu, Qing. 1997. First report of *Pratylenchus thornei* from spring wheat in southern Ontario. Can. J. Plant Pathol. 19:289–292.

Addendum:
Biology of Root-lesion Nematodes

Root-lesion nematodes are microscopic roundworms with complex organ systems. There are approximately 40 species described in the genus *Pratylenchus*. Root-lesion nematodes are distributed throughout the world and damage a broad range of crops, including most crop species produced in the inland PNW: wheat, oat, barley, corn, pea, lentil, canola, mustard, potato, alfalfa, apple, and others. Wheat and chickpea are especially favorable hosts. Reports of significant damage to small grains have been recent, mostly since 1980. Yield losses up to 85 percent have been measured on wheat in Australia.

Root-lesion nematodes live freely in soil as migratory endoparasites, meaning that they may become entirely embedded in root tissue but never lose their ability to move from place to place in the root or to move back into soil. These nematodes penetrate roots by puncturing and entering the surface cells (epidermis) and then migrating throughout the root cortex. This results in surface lesions that favor greater colonization by fungal root-rotting pathogens and saprophytic bacteria, fungi, and nonparasitic nematodes which cause more extensive rotting and discoloration. These activities reduce the ability of roots to produce branches and absorb water and nutrients.

Symptoms

Nematodes enter plants soon after seed germination, but root symptoms may not be detected until plants are older than 6 to 8 weeks. The main symptoms include reduced numbers or lack of lateral branches along main roots and dark lesions on the roots. Outer layers of root tissue (the cortex) disintegrate. Root symptoms are difficult to detect in the field, especially for cereals, and are confused easily with or masked by symptoms of Pythium root rot and Rhizoctonia root rot. Affected areas of fields appear unthrifty, yellow (especially lower leaves), or droughty. Symptoms easily are confused with nitrogen deficiency, drought, or barley yellow dwarf.

Yield reductions and root damage cannot be proven without studies using nematicides, soil fumigation, or resistant and susceptible varieties. Relationships between lesion nematode populations and yield reductions are difficult or impossible to generalize over large regions, because yield responses are influenced strongly by climate, plant, and soil factors.

The Nematodes

Root-lesion nematodes appear worm-like under the microscope. They are about 0.5 mm (0.02 inch) long and move (•swim•) in water films covering soil particles. They remain active at soil moisture contents below limits for germinating seed. Three species common to nonirrigated crops in the inland PNW include *Pratylenchus thornei, P. neglectus,* and *P. penetrans*. Species identification requires the services of a professional nematologist.

Disease Cycle

Root-lesion nematodes are motile within root tissue and soil. Females deposit about one egg per day and eggs hatch in 1 week. Juveniles go through about four molt stages within 35 to 40 days before becoming adults. All juvenile and adult stages are parasitic, and numbers in roots increase exponentially through the growing season. Older, dying root tissues are vacated as nematodes constantly search for young cells. These nematodes survive in an inactive, dehydrated state in roots and soil during dry or freezing conditions. They become active again when moisture, roots, and favorable temperatures return. Some species of *Pratylenchus* are more common in sands and others in clays, but the genus is not strongly restricted by soil or climate.

Control

Lesion nematode populations decline during summer fallow and are usually low in cultivated wheat/fallow rotations. Populations can become very high in direct-drill systems, especially if susceptible crops and varieties are grown repeatedly. The best control is achieved by rotations that include resistant hosts that restrict the rate of nematode reproduction. Small grain varieties vary greatly in resistance to damage.